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ABSTRACT

The lives and mathematical contributions of seven famous women mathematicians are presented. They are: Hypatia, Agnesi, Sophie Germain, Mary Somnerville, Augusta Lovelace, Sofya Kovalevsky, and Emmy Noether. (MP)

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REDISCOVERING WOMEN MATHEMATICIANS

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Before looking at the lives of individual women, it is important to note some of their common characteristics.

Most of the women included in this paper came from, at the very least, middle class families with educated male parents. The women themselves generally had non-formal educations and were often self taught, because they were unable to obtain educations at standard institutions. All the women encountered opposition to their studies, both from their own families and the formal educational systems of their times. Some were able to find a mathematical mentor who aided them with their education. All the women to be described received some limited recognition in their lifetime which is why the paper is entitled "Rediscovering Women Mathematicians."

Hypatia (370 A.D. - 415 A.D.) is the earliest known woman in the history of mathematics. She is known mainly from the letters of her students, primarily Synesius, Bishop of Libya.

Hypatia was the daughter of a professor at the University of Alexandria, where she also became a professor in mathematics, philosophy and astronomy. Hypatia was, at this time, (400 A.D.) the head of the Neoplatonist school which caused her troubles with the church.

There are three major works attributed to Hypatia by Synesius. All were lost in the burning of the Library of Alexandria. They include: a commentary on the Arithmetica by Diophantus, a treatise on the conic sections of Apollonius,

and a commentary on Ptolemy, the Astronomical Canons. The invention of several scientific devices is also attributed to her.

As previously noted, Hypatia's relations with the church were poor. Her scientific rationalism ran counter to the beliefs of the dominant Christian religion. She was considered a heretic and when the Bishop of Alexandria begin his oppression of heretics, she was included. Hypatia was pulled from her carriage, tortured and murdered in 415 A.D. when she was 45. It is ironic to note that part of the manuscript of the Arithmetica is now found in the Vatican Museum.

The major contribution of Maria Gaetana Agnesi (1718 - 1799) was the writing of the first comprehensive calculus text. Agnesi's father was a professor of mathematics at the University of Bclogna. Maria Agnesi had a private tutor, because, as the eldest of twenty-one children, she was expected to tutor her younger brothers.

Maria Agnesi had a special talent for languages and by the age of seventeen, she was able to speak seven languages fluently. This enabled her to successfully host her father's "conversazione." These philosophical discussions, attended by intellectuals from all over Europe, were begun when Maria was fifteen years old. A typical session was recalled by Charles de Brosses, president of the parliament of Burgundy, in his Letters sur Italie. I was "...amazed to hear her speak Latin with such purity, ease, and accuracy...." "The conversation afterwards became general, everyone speaking in the language of his own country, and she answering in the same language."[1]

Although successful as a hostess, Agnesi was not comfortable in large groups, so on her twentieth birthday, she requested permission to enter a convent. This request was denied by her father but she was permitted to lead a quieter life and pursue her studies.

The Propositiones Philosophicae, a collection of essays on the natural sciences and philosophy, was the first project that Agnesi completed.

Agnesi's second project was a mathematical work that took her ten years to complete. Intended as a mathematics text for her brothers, the Analytical Institutions developed into two large quarto volumes on differential and integral calculus. The text is divided into four books. The first book, Finite Quantities, contains algebra and geometry. Book two, Infinitely Small Quantities, is on differential calculus and book three is on integral calculus. The fourth book, Inverse Method of Tangents, is on simple differential equations.

The Analytical Institutions was translated into both French and English. Following the appearance of the French version, the French Academy of Science wrote in their notes: "We regard this as the best and most complete text that has been done of this type."[2]

The English translation of the text is responsible for the misnomer, "The Witch of Agnesi." Appearing in 1801, the English version was translated by J. Colson of Cambridge, who learned Italian specifically to translate Agnesi's text. In the conics section Agnesi discussed the curve $y^2x + a^2(x-a) = 0$. For this plane cubic curve, Agnesi used the name versiera from

the Latin verb vertere, meaning to turn. Colson confused this with the Italian word avversiera, translated as "wife of the devil." This mistranslation provided the "witch of Agnesi," which is still found today, only in English texts.

Following her father's death in 1752, Maria Agnesi devoted the remaining years of her life to charitable work.

Sophie Germain (1776 - 1831), the first woman to do original mathematical research, was born into a wealthy Parisian family. She was thirteen years old during the French Revolution and so she spent most of her time indoors. To occupy herself, Sophie Germain studied in her father's library. After reading about Archimedes' death, she was inspired to study mathematics.

The Germain family opposed these studies and gave their daughter no help. Thus, young Sophie sat alone, untutored in the library and read all the mathematics books. She learned Latin in order to read Newton and Euler. Watching Sophie study so diligently, her parents became concerned for her health and, to prevent further study, they denied her light and heat and confiscated her clothing at night in order to force her to sleep. To thwart her parents, Sophie wrapped herself in a quilt and studied with hidden candles all night. On discovering their daughter asleep over a slate full of calculations, the Germain family relented and let Sophie study.

The École Polytechnique opened in 1794. Although women students were not accepted, the new practice of presenting compositions to a professor for criticism had been instituted.

Without any formal mathematical training, Sophie Germain submitted her personal observations on Lagrange's notes. Fearing ridicule as a learned woman, she signed her observations "Le Blanc, pupil at the École Polytechnique." Lagrange felt that the work of Le Blanc was so outstanding that he wanted to meet him. When he met Sophie, he was shocked and became her advisor.

Sophie Germain's primary interest was in number theory. She studied Gauss' Disiquisitiones Arithmeticae when it appeared in 1801 and sent him her work. Since women were not taken seriously, she again used the Le Blanc pseudonym. The Disquisitiones is quite incomprehensible and Gauss himself was impressed by the work of the young Parisian student Le Blanc. He wrote to his friend Olbers:

> "Recently I've had the joy of receiving a letter from a young Parisian geometer, Le Blanc, who is familiarizing himself enthusiastically in the higher arithmetic and gives proofs that he has penetrated deeply into my Disquisitiones Arithmeticae."[3]

Sophie Germain continued to correspond with Gauss under the name of Le Blanc for six years. Her secret identity was revealed in 1807 when the French besieged Breslau, near the Gauss home. Sophie, concerned about Gauss, had a French general look in on Gauss. Having never heard of Sophie Germain, Gauss was quite confused by the visit. This situation was clarified in a series of letters.

In response to Sophie's explanation, Gauss wrote in 1807:

> "...the enchanting charms of this sublime science reveal themselves only to those who have the courage to go deeply into it. But when a person of the sex which, according to our customs and

> prejudices, must encounter infinitely more difficulties than men..., succeeds nevertheless in surmounting these obstacles..., then without doubt she must have the noblest courage, quite extraordinary talents and superior genius."[4]

To his friend Olbers, Gauss expressed his surprise differently. "That Le Blanc is a mere assumed name of a young lady, Sophie Germain, certainly amazes you as much as it does me."[5] In response to a letter from Gauss, Bolyai jokingly wrote: "You once wrote me of a Sophie in Paris; if I were your wife, I would not be too pleased. Write me more of her."[6]

Sophie Germain's most important research was in number theory. She proved Fermat's Theorem for n an odd prime less than 100.

Germain's remaining research was in mathematical physics, specifically the theory of surfaces. Since 1809, the French Academy of Sciences had offered a prize for the solution to the problem of the vibration of elastic surfaces. Germain attempted to solve this problem. Her memoir in 1811 was rejected but she received an honorable mention in 1813. In 1816, Germain received the Grand Prize for her "Memoir on the Vibrations of Elastic Plates." The equation which won the prize,

$$N^2\left[\frac{\partial^4 z}{\partial x^4} + 2\frac{\partial^4 z}{\partial x^2 \partial y^2} + \frac{\partial^4 z}{\partial y^4}\right] + \frac{\partial^2 z}{\partial t^2} = 0,$$

now has only historical significance. However, it is important to note that the woman who derived it had no formal training in mathematics.

As a result of the Grand Prize, Sophie Germain was invited to be a member of the French Academy. She wrote several more papers on elasticity and number theory before she died of breast cancer in 1831.

Sophie Germain received no public recognition. Her death certificate called her an annuitant, someone living on an inherited income, not a mathematician. Gauss had attempted to obtain an honorary degree from Göttingen for Germain, but her death came before it could be awarded. At the centenary celebration of Göttingen in 1837, Gauss regretted that Sophie Germain was no longer alive to receive a degree, for "She proved to the world that even a woman can accomplish something worthwhile in the most rigorous and abstract of the sciences and for that reason, would have well deserved an honorary degree."[7]

Mary Fairfax Somerville (1780 - 1872) did not begin her education until late in life. Fortunately, she had a long life in which to make up for lost time. Partially because of her own difficulties in obtaining an education, she was very involved in popularizing science to the people.

Mary Fairfax was born in a small seaport town near Edinburgh, as her father was a British Naval officer. Mary received no education and was unable to read until the age of ten. She later taught herself writing, arithmetic, and Latin.

When she was fourteen, Mary saw an algebra problem in a fashion magazine that aroused her curiosity about the "queer" combination of x's and y's. With no one available

for explanation, she used the family library. At a late: time, her brother's tutor found her an algebra book and a copy of Euclid. Mary's father opposed this study and ordered the candles removed from her room. To continue her learning, Mary memorized the geometry theorems and repeated them to herself in the dark. However, her studying was stymied by her marriage to a man who opposed the education of women, when she was twenty-four.

On her husband's death in 1807, Mary became financially independent and, at the age of twenty-seven, she began to seriously study mathematics and astronomy. At thirty, she purchased her first mathematical library. She stated: "I could hardly believe that I possessed such a treasure when I looked back on the day that I first saw the mysterious word 'algebra', and the long years in which I persevered almost without hope. It taught me never to despair. I had now the means, and pursued my studies with increased assiduity."[8]

In 1812, at the age of 32, Mary was married to Dr. Somerville who was supportive of her endeavors. That year, she also published her first paper, a discussion of a problem on Diophantine Equations.

In 1826, when she was 46, Mary Somerville presented the results of her experiments on "The Magnetic Properties of Violet Rays of the Solar Spectrum" to the Royal Society of London.

In the following year, she was asked to translate into English Laplace's Celestial Mechanics and Newton's Principia.

The assignment was accepted with the condition that if she failed, the manuscript would be destroyed and her work kept secret. At the age of 47, with little formal mathematical training, Mary Somerville had reason to be nervous. In addition, she had never really writen and had three young daughters at home. She wrote:

> "I rose early and made such arrangements with regard to my children and family affairs that I had time to write afterwards; not, however, without many interruptions. A man can always command his time under the plea of business; a woman is not allowed any such excuse..."[9]

Nonetheless, Somerville finished the translation in less than a year and added some of her own comments. The work, entitled, The Mechanism of the Heavens, was accepted for publication in 1831. The book was used as a text at Cambridge and Somerville received a government pension for her scientific contributions. She was also, at this time, elected an honorary member of the Royal Astronomical Society, one of the first two women.

Having established her reputation, Somerville devoted herself to popularizing science and wrote several textbooks.

In 1860, following the death of her husband, Somerville moved to Italy where she remained until her death. To occupy herself at this time, her eighty-first year, she began a new book. Molecular and Microscopic Science was published in 1869 when Somerville was 89 years old. Three years later, she died and was buried in Naples.

In recognition of her contributions to science, the women's college at Oxford was named Somerville College.

An added contribution made by Mary Somerville was the introduction of Augusta Ada Byron Lovelace (1815 - 1852) to mathematics.

Augusta Byron, the first computer programmer, was born in England to Lord Byron and Annabella Milbanke. Her parents separated after her birth and Augusta was not permitted to see her father after her second birthday. As her inclinations were more mathematical than literary, Augusta Byron received mathematics tutoring when she was fourteen.

When she was sixteen, Augusta Byron was taken to a party at the home of Charles Babbage, inventor of the Difference Engine, the forerunner of the computer. A small model of the invention was kept in the Babbage home. Most visitors admired it as a lovely art work, but Augusta was excited by the mechanics of the machine. Sophia De Morgan, who had accompanied Augusta to the party wrote, "While other visitors gazed at the working of this beautiful instrument with the sort of expression, ...savages (show) on first seeing a looking glass...Miss Byron, young as she was, understood its workings and saw the great beauty of the invention."[10] Following this introduction, Augusta Byron frequented the Babbage house, to study the machine and its applications.

At nineteen, Augusta Byron married. Following the marriage to Lord Lovelace, Augusta maintained her correspondence and working arrangements with Charles Babbage.

Because the English Government had mocked the Difference Engine, Babbage presented his new invention in Italy. A description of the Analytical Engine was published at that time, October 1842, by L. F. Menabrea.

In the meantime, Lovelace had just given birth to her third child and was ready to study mathematics. She obtained tutoring on the subject of finite differences in order to work with the Analytical Engine. A year later, June 1843, Lovelace translated Menabrea's "Sketch of the Analytical Engine Invented by Charles Babbage." She then began to annotate the article. This resulted in a paper, "The Notes", which was longer than the original Menabrea paper.

At that period, it was considered unfeminine for a woman, especially a countess, to sign a literary work. Although Babbage wanted "The Notes" published as an original paper, Lovelace felt that she had promised the journal a complete paper with notes. Thus the paper was published with the initials A. A. L. in August 1843. The identity of A. A. L. was not revealed for thirty years.

Following the completion of the paper Babbage wrote to Lovelace: "These memoirs taken together furnish, ..., a complete demonstration that the whole of the developments and operations of analyses are now capable of being executed by machinery."[11] With her detailed descriptions of how to use the machine, Augusta Ada Lovelace qualifies to be called the first computer programmer.

"The Notes" contains explanations of how to use the Analytical Engine to do mathematics. It contains cards with

programs detailing the computations. After reading the paper, the mathematician, A. De Morgan, a family friend, wrote to Lovelace's mother that her daughter showed the makings of "...an original mathematics investigator, perhaps of first rate eminence."[12] He compared her to Maria Agnesi but warned her mother not to encourage this interest because it would be harmful to a person not physically strong.

"The Notes" was also acclaimed by the scientific community and Babbage's reputation was enhanced.

Lovelace spent the remainder of her life working on applications of the Analytical Engine. She died at the age of thirty-six and was buried, at her request, in the Byron vault in Nottingham.

Sofya Krukovsky Kovalevsky, (1850 - 1891), encountered difficulties which would have discouraged a less determined person. After obtaining an education, she was denied an opportunity to teach or publish and when she was finally able to do these things, it was in a foreign country and in languages other than her native Russian.

Sofya Krukovsky was born in Moscow to a Russian Army officer. General Krukovsky opposed the mathematical training of girls, so when he found his daughter studying algebra when she was thirteen, he hid her books. In response, Sofya smuggled a copy to her room and taught herself.

When Sofya was fourteen, a neighbor, physics professor Tyrtov, left a copy of his new text at the house. While studying the text, Sofya found that she needed trigonometry and worked it out herself. When Tyrtov viewed the work of the

young Sofya, he found that she had developed the trigonometric functions independently, in exactly the same way that they had been developed historically. Professor Tyrtov, duly impressed, persuaded General Krukovsky to allow Sofya to study mathematics at the nearby Naval Academy.

Attending the university was the next step after the Naval Academy. However, the Russian University system was closed to women and General Krukovsky would not give his daughter permission to study abroad. To obtain her freedom, Sofya made what was called a "fictitious" marriage to Vladimir Kovalevsky. She then left Russia to pursue her studies.

Arriving in Berlin to study with Weierstrass, Kovalevsky found the university closed to women. She personally requested Weierstrass to admit her to his classes. After watching Kovalevsky solve a set of problems in hyperelliptic functions that he presented at the interview, Weierstrass attempted to have her admitted to the university but was rebuffed. Not wanting to lose this mathematical talent, Weierstrass offered to privately tutor Sofya Kovalevsky. The tutoring began in the fall of 1870 and lasted for four years.

By 1874, Kovalevsky had completed three original works, any one of which Weierstrass felt was suitable for a doctoral dissertation. Weierstrass was able to convince the University of Göttingen to award Kovalevsky a Ph.D. in absentia, which was done in July 1874. Without ever appearing for orals or defense, Sofya Kovalevsky received a Ph.D., summa cum laude, solely on the basis of her research and Weierstrass' recommendation.

The paper published as her dissertation in 1875 was, "On the Theory of Partial Differential Equations." Her other two papers were not published for ten years because Kovalevsky was unable to obtain either a job or recognition.

With nothing left to do, Sofya Kovalevsky returned to Russia, where she consummated the marriage to Vladimir and had a daughter.

In Russia, the only mathematics position available to women was to teach arithmetic in the lower grades of a girls school and, according to Sofya, "I was unfortunately weak in the multiplication tables."[13]

Kovalevsky's return to mathematics was spurred by Chebyshev's invitation to give a paper at the scientific congress being held in St. Petersburg in 1880. Following the presentation of her paper on Abelian Integrals, Gosta Mittag-Leffler offered to look for a position for Kovalevsky in Sweden.

In 1883 while Kovalevsky was in Berlin doing research on the "Refraction of Light in a Crystalline Medium", her husband committed suicide.

Fortunately, at this time, a job opening appeared in Sweden. Mittag-Leffler was able to get Kovalevsky a position, but not without conditions. In order to prove her competence, Kovalevsky would have to teach for one year without either salary or official affiliation with the university.

Kovalevsky's arrival in Sweden in 1883 was met with a great deal of controversy. A. Strindberg wrote in the newspaper: "A female professor is a pernicious and unpleasant

phenomenon - even, one might say, a monstrosity..."[14] Nonetheless, Kovalevsky lectured in the spring of 1884 and received an official appointment in July 1884.

In 1888, the French Academy of Sciences offered a prize for a general solution to the problem of the rotation of a rigid body about a fixed point. Kovalevsky's paper on this problem was one of fifteen submitted anonymously for the Borodin Prize competition. Of the fifteen, one was considered so outstanding that the usual prize of 3,000 francs was increased to 5,000 francs. The prize for the paper, "On the Rotation of a Solid Body About a Fixed Point", was awarded to Sofya Kovalevsky in December 1888.

Unsuccessful in her search for a new position, Kovalevsky renewed the professorship at Stockholm in 1889.

In addition to her mathematical research, Kovalevsky, at this time, had several popular novels published in Sweden. Often asked how a mathematician could also be interested in literary pursuits, Kovalevsky replied:

> "Many who have never had an opportunity of knowing any more about mathematics confound it with arithmetic, and consider it an arid science. In reality, however, it is a science which requires a great amount of imagination, and ...it is impossible to be a mathematician without being a poet in soul."[15]

At this time, Kovalevsky had another love in her life, an expatriate Russian lawyer living in France. Returning home from one of her frequent visits, she became ill. The illness was misdiagnosed and before it was corrected Sofya Kovalevsky died at the age of forty-one.

After her death, Weierstrass burned all her letters for he felt that, "'People die, ideas endure': it would be enough for the eminent figure of Sofya to pass into posterity on the lone virtue of her mathematical and literary work."[16]

The mathematician who could be called the "mother of modern algebra", Emmy Noether (1882 - 1935), was born in the German university town of Erlangen, where her father was a mathematics professor. The young Noether received a typically female education and in 1900, she passed the Bavarian state teacher's exams. However, after passing the exams, she decided to attend the university.

At this time, a woman who wanted to enroll as a special student was required to pass an entrance test. The women's schools did not prepare you for these exams so it was necessary for Emmy Noether to audit courses. She audited for two years at Erlangen and passed the matriculation exam in 1903.

Noether enrolled at Gottingen but after a year she returned to Erlangen. In July 1908, Noether received her degree summa cum laude from Erlangen. Her dissertation was very much in the style of her advisor, full of formal computations. This is in sharp contrast to her later works which were not the least bit computational.

Noether worked for eight years at Erlangen without either pay or a formal appointment. Because of her work in invariant theory, Noether was invited by Hilbert to Göttingen. To receive an appointment there, the entire faculty had to approve. In considering Noether, they protested: "What will the soldiers think when they return to the university and find that

they are expected to learn at the feet of a woman."[17] Hilbert answered: "I do not see that the sex of the candidate is an argument against her admission as a Privatdozent (lecturer). After all, the (faculty) senate is not a bathhouse."[18]

Noether did not receive an appointment so to enable her to lecture, the series was announced under Hilbert's name but given by Noether.

Following World War I, Noether was permitted to lecture under her own name as a faculty member, but she received only an honorific title with no pay. Two years later, she received a lectureship in algebra which carried a small stipend.

In 1920, Noether and W. Schmeidler published a significant paper on differential operators. For the first time, the paper examined the ring of differential operators rather than the manipulation of formal expressions.

Noether's work in algebra included the paper "Theory of Ideals in Rings." In this paper, she generalized the fundamental theorem of arithmetic to the class of commutative rings with ascending chain conditions. As a result, rings with ascending chain conditions on Ideals are called Noetherian Rings. Her contribution to non-commutative algebras and their relation to number theory is indicated by the Brauer-Hasse-Noether Theorem on cyclic algebras.

However, Emmy Noether's most important contribution to mathematics was not her papers but her influence on algebra and her impact on students. Emmy Noether set the style of studying concepts rather than manipulation in algebra. By

1930, she was the center of mathematical activity at Gottingen. Mathematicians from all over the world came to hear her lectures. She was not a "good" teacher and her lectures were not well organized. She would introduce unfinished ideas and discuss them with her students. Obviously, those attending Noether's lectures were already Ph.D.'s and scholars. Among the regular group known as Noether's boys were the Dutch mathematician, Van der Waerden and the Russian professor, Alexandroff.

Alexandroff invited Noether to teach in Moscow and acknowledged her influence after her death. In a memorial address he said,

> "She taught us to think in simple, and thus general, terms: homomorphic image, the group or ring with operators, the ideal--and not in complicated algebraic calculations; and she therefore opened a path to the discovery of algebraic regularities where before these regularities had been obscured by complicated specific conditions."[19]

Thus the reason why Emmy Noether could be called the mother of modern algebra.

In 1933, because she was Jewish, Noether was forced to leave Göttingen. Alexandroff's efforts to get her a position in Moscow were held up by red tape. Noether was invited to America by Anna Pell Wheeler, chairman of the mathematics department of Bryn Mawr College.

Emmy Noether joined the faculty at Bryn Mawr and also gave weekly lectures at the Institute for Advanced Studies in Princeton. After a year and a half at Bryn Mawr, Noether graduated her first Ph.D. student. A short time later, Noether was operated on for a tumor. Seemingly recovering, she died

suddenly of complications at the age of fifty-three. A few days later, the following letter from Albert Einstein appeared in The New York Times: "Within the past few days, a distinguished mathematician, Professor Emmy Noether, formerly connected with the University of Göttingen and for the past two years at Bryn Mawr College, died in her fifty-third year. In the judgment of the most competent living mathematicians, Fraulein Noether was the most significant creative mathematical genius thus far produced since the higher education of women began."[20] This tribute provides a fitting conclusion to this rediscovery of women mathematicians.

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Footnotes (Cont'd)

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